

### Electric Circuit Breaker

The present invention relates to an electric circuit  
5 breaker for protecting an electrical circuit against  
excessive current loads.

Electric circuit breakers are typically used in  
electricity distribution networks at various locations  
10 in the network, in order to monitor the current level  
flowing in the network, and to interrupt the electrical  
current if the current level flowing through the  
electric circuit breaker exceeds certain thresholds or  
limits.

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In order to achieve an adequate protection in the low  
voltage portion of the network, thermo-magnetic circuit  
breakers are generally used. A thermo-magnetic circuit  
breaker inserted in an electrical circuit will  
20 automatically break the electrical circuit to disconnect  
a portion of the network, if the current level through  
the electric circuit breaker exceeds a dangerous level,  
i.e. when an overload condition occurs. In this type of  
circuit breaker, this is typically accomplished by means  
25 of a resistive thermal element which will modify its  
mechanical dimensions with temperature due to the  
increased current level. A thermal element will,  
however, not instantaneously respond to an overload  
condition. Rather, the time required by the thermal  
30 element for varying its mechanical dimensions depends on  
its thermal mass, and on the other hand also on the

amount of overload current. The time required by the thermal element for responding to the particular overload condition accordingly varies between fractions of a second and about one hour. Obviously, also the  
5 ambient temperature has an influence on this response time. The non-instantaneous response characteristics of the thermal element are appropriate for protecting the electrical circuit and thus the entire network against a continuous overload condition caused e.g. by a parallel  
10 connection of too many loads to the electric circuit, whereas short current spikes will not cause an unwanted tripping of the electric circuit breaker. Such current spikes are generated when electric loads like television sets or electric motors are switched on.

15 On the other hand, the non-instantaneous response characteristics make an electric circuit breaker with ; only a conventional thermal element less suitable for protecting its associated network portion against very  
20 high levels of overcurrent which may be caused e.g. by a short circuit condition. In this situation a fast response of the circuit breaker is required.

In order to provide a fast response time in such extreme  
25 overload conditions, a conventional electric circuit breaker for use in the LV network therefore also comprises an electromagnetic element, e.g. a coil, which will generate a magnetic force depending on the amount of current flowing through the circuit breaker. If the  
30 force generated by the magnetic element exceeds a certain force threshold, the magnetic element will trip

the electric circuit breaker with some milli seconds of delay in order to prevent instantaneous damages in the network.

5 Besides this conventional type of thermo-magnetic circuit breaker, other conventional types of electric circuit breakers comprise a thermal element only, or an electromagnetic element only, for breaking the electrical circuit when an overload condition has  
10 occurred.

Each of these and other types of conventional electric circuit breakers has a so-called rated current. This parameter describes the current level beyond which the  
15 circuit breaker is supposed to break the electrical circuit. A current level above the rated current level constitutes an overload condition which will eventually lead to the tripping of the electric circuit breaker. The rated current is determined by the design of the  
20 circuit breaker, e.g. the size, thermal mass, mechanical bias and the like of the thermal and/or electromagnetic elements. Nowadays, a variety of electric circuit breakers is on the market for a variety of different rated currents, adapted to the variety of needs which  
25 arise from the existing variety of types of consumers, load levels and network load constraints. However, one or more of these parameters of an electrical installation may change sometimes for various reasons. In a power distribution network a need may arise to  
30 update the tripping current level or the degree of protection for the circuit protected by the circuit

breaker. To achieve this with conventional circuit breakers, it is necessary to replace the existing electric circuit breaker having a first rated current by another electric circuit breaker having another rated  
5 current adapted to the new situation. This is laborious, time consuming and can be particularly disadvantageous in large electricity distribution networks. A change of the tripping current level during the ongoing operation of the circuit breaker is impossible.

10 The necessity to provide and install a variety of different circuit breakers with a variety of given rated currents leads to inflexibilities with adverse impacts on the costs for network maintenance and administration. More flexibility in this regard would be highly  
15 desirable.

The present invention has been made in order to solve these and other problems associated with the prior art. An electric circuit breaker according to an embodiment  
20 of the present invention comprises a switch to be arranged in the electrical circuit which is to be protected against excessive current loads. The circuit breaker furthermore comprises first means for causing said switch to break the electrical circuit in response  
25 to a tripping signal. Means are provided for receiving and storing a programmable current threshold command. The circuit breaker detects a current level in the electrical circuit, and processing means are provided for generating said tripping signal depending on said  
30 stored current threshold command and said detected current level.

This embodiment of an electric circuit breaker according to the present invention is advantageous in that the load protection characteristics of the circuit breaker  
5 are provided programmable. In this way an electric circuit breaker is obtained which is suitable for a variety of consumers, load levels and network load constraints, without the need to perform replacement work or to keep a large number of different types of  
10 circuit breakers available.

The programming of the electric circuit breaker can be performed in a variety of different ways. Preferably, the electric circuit breaker includes power line  
15 communication means for receiving current threshold commands via the electric circuit protected by the circuit breaker. Such received current threshold commands are stored by the electric circuit breaker until another current threshold command is received.  
20 Such commands can be generated by a central facility for administering a given network section which comprises a plurality of consumers and associated electric circuit breakers. It is advantageous to adapt the central facility such that individual current threshold commands  
25 can be addressed to individual circuit breakers in the network section. This will allow the network operator to remotely administrate an individual consumer connected to a particular electric circuit breaker with a high degree of flexibility and low administration costs. For  
30 example, changes in the supply contract relating to the maximum admissible current consumption can be

implemented quickly by reprogramming the electric circuit breaker by remote administration.

In addition or alternatively, it is furthermore  
5 advantageous to provide the central facilities such that a current threshold command can be addressed to a group or to all of the electric circuit breakers in the network section. By way of example, in response to the occurrence of a global overload condition in the entire  
10 network section administrated by the central facility, appropriate, e.g. lower current thresholds can be programmed into a large number of electric circuit breakers, in order to prevent a global breakdown or blackout without the need to switch off the entire  
15 network section. Such global overload conditions may e.g. occur if a large number of consumers simultaneously draws current from the network section at a level which is close to but below the normal current threshold applicable to the consumers. Similarly, under light load  
20 conditions in the network section it would be advantageous to program higher current threshold into a group or all of the electric circuit breakers of that section in order to allow a higher individual consumption of current for the consumers of that  
25 section.

Alternatively or in addition to the provision of means for receiving programmable current threshold commands via power line communication over the electrical circuit  
30 to which the electric circuit breaker is connected, it can be advantageous to provide the electric circuit

breaker with a user interface to receive programmable current threshold commands from an operator e.g. through a keyboard, or from a programmer device, e.g. a suitably programmed personal computer, through a suitable  
5 standard interface like RS232, USB, blue tooth or the like. Interfaces with a high level of electrical insulation, like flag port devices or in accordance with IEC 61107/EN 61107/IEC62056-21 are particularly advantageous.

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Preferably, said means for receiving a programmable current threshold command is adapted to store a plurality of current thresholds and associated response times as specified by the received current threshold  
15 command. Preferably, said processing means is adapted to generate said tripping signal when the detected current level in the electrical circuit protected by the electrical circuit breaker has continuously exceeded a stored programmed current threshold for a duration  
20 determined by the associated programmed response time. In this way it can be achieved that the response time of the electric circuit breaker is programmable and dependent on the level of overcurrent flowing in the electrical circuit. Preferably, the response times are  
25 programmed to decrease with the associated current thresholds increasing, such that the response time for more severe overload conditions will be shorter than the response time for less severe overload conditions. As an alternative to specifying programmable current  
30 thresholds and/or associated response times in the current threshold command, it can be advantageous to

provide means for storing a plurality of predefined functional relations defining the associated response times for a variety of current levels, and to provide the processing means to select one of these predefined  
5 relations in accordance with the received and stored programmable current threshold command.

As a further alternative, said current threshold command can also be used to specify only the response time until  
10 said processing means responds to one or more predefined stored current thresholds with the generation of said tripping signal which causes said switch to break the electric circuit.

15 Advantageously, the electric circuit breaker furthermore comprises means for receiving a switch command, that is a circuit open command or circuit close command, and ; means for operating said switch to open and close the electrical circuit in accordance with the received  
20 switch command. Such switch command can be transmitted via power line communication and allows a remote control of the electric circuit breaker of individual consumers or of groups of consumers from central administration and control facilities.

25 Advantageously, the electric circuit breaker furthermore comprises second means for causing the switch to break the electrical circuit if a current flowing in the electrical circuit exceeds a predetermined rated  
30 current. According to this embodiment, the switch will be caused to break the electrical circuit if the current



flowing through the electric circuit breaker exceeds a predetermined rated current for more than a given duration. Under normal conditions of the electric circuit breaker, the switch will trip in response to the tripping signal generated by the processing means in accordance with a variable current threshold which can be programmed from the external into the electric circuit breaker. The second means advantageously provides upper response limits associated with current levels above the rated current for the electric circuit breaker to break the electric circuit, in order to take account of the possibility that a fault occurs in the electric circuit breaker and tripping under a load condition above the programmed threshold does not work. Preferably, the second means for causing the switch to break the electrical circuit as well as the switch form an integral unit. It is particularly convenient to also incorporate said first means into this integral unit.

Advantageously, an electric circuit breaker according to the present invention is incorporated in a power meter or energy meter for measuring the electric energy consumption of a consumer. Advantageously, the electric circuit breaker comprises means like a lever or button for enabling an operator to manually break or close the electric circuit.

Further advantageous embodiments of the present invention are defined in the dependent claims.

In the following, specific embodiments of the present invention will be described with reference to the accompanying drawings. In the drawings, similar or corresponding elements have been denoted with the same  
5 reference signs.

Fig. 1 shows an overview of an electric power distribution network comprising a plurality of electric circuit breakers;

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Fig. 2 shows a block diagram of a first embodiment of an electric circuit breaker according to the present invention;

15 Fig. 3a, b show t-I diagrams to illustrate the operation of embodiments of the electric circuit breaker according to the present invention;

20 Fig. 4 shows an embodiment of an electric power distribution network comprising central control facilities;

Fig. 5 shows a second embodiment of an electric circuit breaker according to the present  
25 invention;

Fig. 6 shows a third embodiment of an electric circuit breaker according to the present invention;

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Fig. 7 shows an advantageous embodiment of the element 13 for causing the switch to break the electrical circuit in response to a tripping signal;

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Fig. 8 shows a flow diagram to illustrate the operation of an embodiment of the processing means of the electric circuit breaker;

10 Fig. 9 shows an extension of the flow diagram shown in Fig. 7;

Fig. 10 shows a first embodiment of a hardware implementation of the processing means; and

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Fig. 11 shows a second embodiment of a hardware implementation of the processing means.

Fig. 1 shows a typical electricity distribution network for distributing electrical energy generated by a power plant (not shown) to a plurality of consumers (H1, H2, ..., Hn). The electricity is distributed over a large geographical area by means of a so-called high voltage network HV, which connects the one or more power plants feeding this high voltage network HV with a plurality of so-called primary substations Tp. The primary substations Tp transform the high voltage (e.g. 380kV in Europe) carried over the HV network into a medium voltage of e.g. 20kV for regional distribution of the energy. The medium voltage distribution network MV connects the one or more primary substations Tp with one

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or more secondary substations Ts which transform the medium voltage carried over the MV network into a low voltage carried over a low voltage network LV for distribution to a large number of consumers H1, H2, ..., Hn. In Europe, the typical low voltage level is 220 to 240 volt, depending on national regulations. The three power distribution sub networks, that is the HV network, MV network and LV network, require electric circuit breakers at various locations in order to enable the network to appropriately react to fault conditions like short circuits or temporary overload conditions which would otherwise lead to a destruction of the network. Reference numeral 1 denotes an electric circuit breaker located at the consumer premises of consumer Hn.

Reference numeral 2 denotes a supply line connecting the consumer Hn with the LV network. F denotes a fuse provided in the line 2 for safety reasons in order to prevent that an excessive current I causes damage to the LV network. Reference numeral 3 denotes a power supply line at the consumer premises Hn, e.g. a power supply line installed inside a building. Power supply line 3 is connected with the power supply line 2 through the electric circuit breaker 1. The power supply line 3 in turn feeds a plurality of electric loads L1, L2, ..., Lk through switches as appropriate. L denotes a lever arranged at the electric circuit breaker 1 to be externally accessible by an operator, for manually connecting or disconnecting the power supply 3 and the power supply line 2. Structure similar to that what has

been shown in greater detail for the consumer  $H_n$  may be found in the other consumers  $H_1, H_2, \dots, .$

Figure 2 shows a first embodiment of an electric circuit  
5 breaker according to the present invention. In the block  
diagram of Figure 2, reference numeral 1 denotes the  
electric circuit breaker which is connected between the  
power supply line 2 and the power supply line 3 shown in  
Figure 1. The character  $n$  across the power supply lines  
10 2 and 3 and other lines in the electric circuit breaker  
indicates that while for reasons of simplicity a single  
phase arrangement is shown in the figure, a poly phase  
design is not different in principle from the single  
phase design shown in this and other drawings of the  
15 present invention, and that the present description  
applies to single phase power supply systems ( $n = 1$ ) as  
well as to poly phase power supply systems, e.g.  $n = 3$   
Reference numeral 11 in Figure 2 denotes a switch  
connected in series with first means 12 for thermo-  
20 magnetically detecting the level of the current  $I$   
flowing through the power supply line 3. Such thermo-  
magnetic current detector means 12 are as such well  
known in the art, and a detailed description of the  
thermo-electric current detector 12 is, therefore, not  
25 necessary. As indicated by the dotted line in Fig. 2,  
the thermo-magnetic current detector means 12 is  
mechanically coupled with the switch 11 in order to  
cause the switch 11 to break the electrical circuit  
established by the power supply line 3 and its connected  
30 electrically loads, in short the electrical circuit 3,  
if the current  $I$  flowing in the electrical circuit 3

exceeds a predetermined rated current. This predetermined rated current is determined by the design of the thermo-magnetic current detector 12. This element 12 typically comprises e.g. a resistive element not  
5 shown in Figure 2, which will change its temperature in accordance with the current load I. A bi-metal arrangement can conventionally be used to transform the change of temperature into a mechanical displacement which is then taken to trip the switch 11 and break the  
10 electrical circuit 3. The current detector 12 furthermore comprises electromagnetic current detection means mechanically coupled with the switch 11, as indicated by the dotted line in Figure 2. These electromagnetic current detection means can be  
15 implemented e.g. by means of a coil connected in series with the switch 11, such that an electromagnetic force is generated by that coil in accordance with the level of current I flowing in the electric circuit 3. If this magnetic force generated by the current detector 12  
20 exceeds a predefined force threshold determined by the design of the current detector 12 and/or the switch 11, this will cause the switch 11 to break the electric circuit 3. L denotes an externally accessible lever L to enable a user to manually trip the switch 11. A variety  
25 of designs of the switch 11, the thermo-magnetic current detector 12 as well as the electrical and mechanical coupling between the elements 11 and 12 is as such well known in the art and suitable for the present invention.

30 Reference numeral 15 denotes a second means for detecting the level of current I flowing in the

electrical circuit 3. In Figure 2, the means 15 for detecting the current level I is shown to be connected in series with the switch 11 and the thermo-magnetic current detection means 12. R denotes a resistive element in series with the electric circuit 3. Reference numeral 151 denotes an amplifier means for detecting the voltage drop occurring across the resistive element R in proportion with the current level I, and outputting a corresponding current level detection signal CL. At this stage it is important to note that there exists a variety of well known current detection circuits and techniques, and the specific implementation depicted in Figure 2 shall not be construed to limit the current detection means 15 to the implementation shown. As an alternative to the shunt resistor R it would also be possible to adopt a current transformer, e.g. realized by means of an additional winding magnetically coupled with a coil in the current detector 12 which generates the magnetic force for tripping the switch 11 in case of excessive current levels I. This additional winding together with said coil will constitute a transformer in order to implement the current detector 15. Other possibilities of implementing the current detector 15 comprise hall effect devices, magneto resistors and Rogosky coils, all of them being well known as such to be suitable for the design of current detection means.

Reference numeral 13 denotes a means for causing the switch 11 to break the electrical circuit 3 in response to a tripping signal 14. The means 13 preferably comprises an electromagnetic coil for magnetizing a

movable member made from soft iron in accordance with the tripping signal 14. Upon magnetization, a magnetic force will be exerted upon the soft iron member in the element 13. This member is mechanically coupled with the switch 11, as indicated by the dotted line in Figure 2, such that in response to the tripping signal 14, the element 13 will cause the switch 11 to break the electrical circuit 3. The element 13 can be implemented in a variety of ways in order to achieve the desired function, to trip the switch 11 in response to a tripping signal 14. An alternative implementation of the element 13 exploits the well known effect of magnetostriction and comprises a member made from magnetostrictive material which is subjected to a magnetic field generated by a coil in the element 13 which receives the tripping signal 14, such that upon this tripping signal 14, the magnetostrictive element will change its mechanical dimensions. This element is mechanically coupled to the switch 11, such that the switch 11 will trip upon the application of the tripping signal 14 to the element 13.

Reference numeral 17 denotes a means for receiving a programmable current threshold command CC. This current threshold command is an external command, that is a command not generated autonomously by the electric circuit breaker 1. This current threshold command CC is received by a suitable communication interface IF in the means 17 and then passed on to a memory MEM wherein the received current threshold command can be stored. The communication interface IF can be a power line



communication interface for receiving current threshold commands CC through the power supply line 2 and the LV network connected to the power supply line 2. The communication interface IF can also be designed to  
5 receive current threshold commands CC through a standard communication interface like RF 232 or USB or some kind of proprietary wire based or infrared or blue tooth interface for communication with a hand held programming device or a personal computer (PC). Alternatively or in  
10 addition, the communication interface IF can comprise a key pad for receiving current threshold commands CC through manual user input, preferably in encrypted form or subject to successful user authentication in order to avoid an unauthorized or illegal access to the means 17  
15 for receiving programmable current threshold commands.

Reference numeral 16 denotes processing means which , receive information CL regarding the detected current level from the current detection means 15, and which  
20 processing means furthermore receive information about the current threshold command stored in the memory MEM of the current threshold command receiving and storing means 17. The processing means 16 outputs the tripping signal 14 as a result of processing operations which  
25 depend upon the input of the current level information CL and the current threshold command stored in the memory MEM, and preferably also depending upon temporal characteristics of the detected current level CL, as will be explained in greater detail further below. The  
30 processing means 16 may be implemented in hardware or by means of suitably programming a micro controller. The

processing means 16 also comprises driver circuitry to drive the element 13, specific embodiments of which will be shown below. If a micro controller is adopted for implementing the processing means 16, the micro  
5 controller can also take over at least some of the functions of the current threshold command receiving and storing means 17. Embedded micro controller solutions are available on the market, comprising on chip interfaces which can be used to implement the command  
10 receiving interface IF of the element 17.

In order to explain the operations performed by the processing means 16 in greater detail by way of example, reference will be made in the following to the diagram  
15 shown in Figure 3a.

Figure 3a shows a t-I diagram to illustrate the reaction of the electric circuit breaker to various load conditions, that is levels of current flowing through  
20 the circuit breaker. The horizontal axis of this diagram indicates the level of current I, while the vertical axis of this diagram indicates the response time t of the circuit breaker for a given current level I.

25 In Figure 3a, reference numeral 31 denotes a first section of a curve representing a functional relation between current levels in a current interval between  $I_R$  and  $I_2$  and the associated response time. Reference numeral 32 denotes a second section of the curve for  
30 current levels above  $I_2$ . The curve 31, 32 describes the

behaviour of the thermo-magnetic current detector 12,  $I_R$  denoting the rated current of the current detector 12. Curve sections 331 to 333 for current intervals between  $I_3$ ,  $I_4$ ,  $I_5$ , respectively on the one hand and  $I_1$ , on the  
5 other hand, as well as the curve section 334 for currents between  $I_1$  and  $I_2$ , describe the behaviour of the current detector 15, processing means 16 and triggering means 13. In the following, the operation of the circuit breaker shown in Figure 2 will be explained  
10 with reference to these curves shown in Figure 3a.

In this embodiment, the electric circuit breaker stores in the memory MEM in the command receiving and storing means 17 a current threshold command CC which identifies  
15 one of the curves 331, 332 and 333 associated with respective current thresholds  $I_3$ ,  $I_4$ ,  $I_5$ , respectively. This current threshold command was previously received from the external through the command interface IF of the electric circuit breaker. In order to explain the  
20 operation of the electric circuit breaker, at first an operating condition is assumed, that the load current  $I$  through the electric circuit breaker is below the programmed current threshold, say  $I_4$  in Figure 3a, presently stored in the memory MEM. In this case, the  
25 processing means 16 will apply a characteristic curve 332 defined by the stored current threshold command  $I_4$ . Since the current load is below the current threshold  $I_4$ , the processing means 16 will not generate a tripping signal, and the switch 11 will remain closed such that  
30 the current  $I$  will continue to flow. Assuming now the

occurrence of an overload condition resulting in a current  $I$  larger than the programmed current threshold  $I_4$ , the processing means will process the detected current level reported from current detector 15 in accordance with the programmed current threshold  $I_4$  by means of measuring the time for which this overload condition continuously prevails. If the duration of the overload condition reaches the response time associated with the detected current level  $I$ , as represented by curve 332, the processing means will generate the tripping signal 14 which will cause the switch 11 to break the electric circuit and hence, terminate the flow of current in the electric circuit 3. In the example shown in Figure 3a, an overload condition in the interval between  $I_4$  and  $I_1$  will result in a response time between about 200 seconds for current level just above the programmed threshold  $I_4$ , and about 100 seconds if the current level approaches  $I_1$ . In other words, the processing means 16 is adapted to generate the tripping signal in response to a detected overload condition in such a way, that the response time also depends on the amount of overload. In the exemplary diagram of Figure 3a, all the three curves 331, 332 and 333 join a curve 334 at the current level  $I_1$ . If an overload condition above the threshold  $I_1$  is detected by the current detector 15 in Figure 1, the processing means 16 will generate the tripping signal 14 as soon as the overload condition above the threshold  $I_1$  has prevailed for more than about 1 sec., as represented by the curve section 334. The response times  $t$  associated with the various

current levels may be predefined, or they may be provided programmable by means of the current threshold command CC.

- 5 The curve section 31 represents the function of the thermal element in the thermo-magnetic current detector 12 shown in Figure 2. From Figure 3a it is evident, that due to the operation of the processing means 16 in conjunction with the current detector 15 and the
- 10 tripping means 13 as just described, the thermo-magnetic current detector 12 should not get the opportunity to cause the switch 11 to break the electric circuit, because for a given overload condition, the processing means 16 will generate the tripping signal 14 with a
- 15 shorter response time than the thermal response time depicted by the curve section 31 of the thermo-magnetic current detector 12. In the embodiment shown in Figure 3a, only for extremely high overload conditions approaching the magnetic force threshold  $I_2$  of the
- 20 thermo-magnetic current detector 12, the response time of the thermo-magnetic current detector 12 and in particular the response time of the electromagnetic components of that current detector 12, will be shorter than the response time of the processing means 16.
- 25 Accordingly, the thermo-magnetic current detector 12 offers a backup function to make sure that the electric circuit breaker will respond to overload conditions with an interruption of the electric circuit 3 even if a fault occurs in any of the elements 13 to 17 shown in
- 30 Figure 2.

In the specific example shown in Figure 3a, the current threshold  $I_1$  may be predetermined in order to provide a fixed upper current limit. It may coincide with the rated current  $I_R$  of the thermo-magnetic current detector 12, because in this example, any load condition above the current level  $I_R$  will by virtue of the thermo-magnetic current detector 12 cause the switch 11 to break the electrical circuit 3, unless the processing means 16 causes an earlier tripping of the switch 11. It is important to note that this specific example shall not be construed to limit the invention in any way. Of course, it is possible to adapt the current thresholds  $I_1$  to  $I_5$  shown in Figure 3 to a variety of different needs in accordance with the particular design without departing from the principles of the present invention. It is, however, preferable to program the electric circuit breaker such that the programmed t-I curve remains below the curve sections 31, 32 of the thermo-magnetic current detector 12.

While the embodiment of Figure 3a provides a single programmable current threshold only, it can be advantageous to adapt the processing means 16 such that the current threshold command CC identifies individual t-I curves to be applied by the processing means 16 in processing the information about the detected current level CL. The plurality of curves available for selection can be defined in the processing means 16 or in the current threshold command receiving and storing means 17 in the form of tables or in the form of

mathematical equations characterizing the set of curves in parameterised form.

Figure 3b shows another example of a  $t$ - $I$  curve adopted  
5 by the processing means 16. In this embodiment, not only the current thresholds  $I_1$ ,  $I_3$ ,  $I_4$ ,  $I_5$  are provided programmable, but also the response times  $t_1$ ,  $t_3$ ,  $t_4$ ,  $t_5$  associated with the current intervals between adjacent thresholds, as depicted in Figure 3b. In this  
10 embodiment, a current threshold command CC contains at least one current threshold  $I_j$  and at least one associated response time  $t_j$ . While all current thresholds  $I_1$ ,  $I_3$ ,  $I_4$ ,  $I_5$  are shown to be less than  $I_R$ , this is not mandatory. Current thresholds above  $I_R$  can  
15 be programmed with associated response times below the curve 31, 32 in Fig. 3b.

Figure 4 shows an embodiment of an electric power distribution network comprising central control  
20 facilities for generating current threshold commands CC. In Figure 4, elements similar to the elements shown in Figure 1 have been denoted with the same reference signs. With respect to these elements, reference is made to the description for Figure 1 in order to avoid  
25 repetitions.

In Figure 4, S denotes a secondary substation for transforming the voltage carried on the medium voltage network MV into the low voltage carried on the low  
30 voltage network LV. To this end, the secondary

substation S comprises a transformer Ts as described above. CBT denotes communication means associated with the secondary substation S. The communication means CBT can generate current threshold commands addressed to individual ones or to specified groups of electric circuit breakers 1 at the consumer premises H1, H2, ..., Hn which are connected to the LV network section supplied by the secondary substation S. Reference numeral 24 denotes a coupling means, e.g. a coupling capacitor, for coupling the current threshold commands CC generated by the communication means CBT to the power supply line 2 of the LV network. Accordingly, in the embodiment shown in Figure 4, the LV network section supplied by the secondary substation S not only serves to distribute electrical power to the consumers H1, H2, ..., Hn, but also serves as a communication medium for transmitting the current threshold commands CC to individual electric circuit breakers 1. In this embodiment, the communication means CBT comprise means for detecting the present load condition of the network section. The communication means CBT comprises suitable processing facilities to process the detected load condition, that is the power presently supplied by the secondary substation S to its LV network section, in order to generate appropriate current threshold commands to selected ones or to all electric circuit breakers 1 at the consumer premises H1, H2, ..., Hn of that LV network section. If the overall load condition approaches a current limit or power limit e.g. of the secondary substation S, the communication means CBT is programmed to generate current threshold commands and



broadcast them via the LV network section to the consumers H1, H2, ..., Hn of the network section. The electric circuit breakers 1 at the consumer premises receive the broadcast current threshold command and  
5 store it in their memory MEM. In this way, as a reaction to a critical load situation in the entire LV network section of the secondary substation S, all electric circuit breakers 1 can lower their current thresholds such that only the consumers presently drawing a large  
10 amount of current will be disconnected from the LV network section. In this way, a complete shut off of the entire LV network section can be avoided. If an effected consumer disconnects some of the loads L1, L2, ..., LK from the power supply line 3, he will be able to  
15 reconnect to the LV network upon operation of the lever L of the electric circuit breaker 1. Accordingly, in the embodiment of Figure 4 the communication means CBT can adaptively control the maximum power which each consumer may draw from the network in accordance with the present  
20 overall load condition, to prevent the occurrence of severe overload conditions which would require the shut down of the entire LV network section. Under light load conditions the CBT will generate appropriate broadcast current threshold commands in order to increase the  
25 current thresholds programmed into the electric circuit breakers 1 at the various consumer premises H1, H2, ..., Hn.

It can be particularly advantageous to distinguish  
30 between different types of consumers. There are some types of consumers, e.g. hospitals, which need to be

supplied with electric power in any case. For other types of consumers, e.g. for normal households, it may be assumed that a temporary reduction of the current threshold will have less severe impacts. Accordingly, it  
5 may be advantageous to provide a consumer type indication together with a programmable current threshold command CC from the communication means CBT, and to store a corresponding predefined type indication in each of the electric circuit breakers in accordance  
10 with the type of consumer. This consumer type indication allows that in order to prevent a complete black out under severe load conditions, the CBT will at first lower the current thresholds of such types of consumers which are less dependent on a guaranteed subscribed  
15 power level, and to gradually extend the reduction of the current thresholds to other types of consumers, if this forms out to be necessary to prevent a complete black out.

20 It is important to note that while this concept has been shown and described with regard to consumers connected to an LV network section supplied by a secondary substation S, the same concept can also be applied in other network portions higher up in the network  
25 hierarchy. E.g., electric circuit breakers programmable as described above, can be provided to protect sections of the MV network, with communication means being located at the primary substations Tp which monitor the present load conditions and which generate appropriate  
30 current threshold commands to the electric circuit breakers in the MV network and/or to the electric

circuit breakers at the consumer premises supplied by the affected MV network section.

Reference numeral 23 in Figure 4 denotes means for  
5 connecting the communication means CBT with central  
administration and control facilities 21 through a  
public wireless telecommunication network 20. The  
central administration and control facilities 21 can be  
provided to administrate larger portions of the network  
10 in a hierarchical fashion, using the communication means  
CBT associated with the secondary substations S as an  
intermediate communication node. The facilities 21 can  
be used to administrate supply contracts, e.g. regarding  
the maximum power subscribed by an individual consumer  
15  $H_i$ , and to program corresponding current thresholds  
and/or response times into the electric circuit breaker  
1 of consumer  $H_i$  in accordance with the contractual  
provisions agreed with the individual consumer  $H_i$ ,  
without the need to have service staff visit the  
20 consumer premises.

Figure 5 shows an embodiment of an electric circuit  
breaker 1 in the electric power distribution network  
shown in Figure 4. In the electric circuit breaker 1 of  
25 Figure 5, elements similar to the elements shown in  
Figure 2 have been denoted with the same reference  
numerals, such that with regard to these elements  
reference can be made to the description given for  
Figure 1.

In the embodiment of Figure 5, the current threshold command receiving and storing means 17 is adapted to receive the current threshold commands CC via power line communication from the power supply line 2 which  
5 connects the consumer Hn to the LV network. Reference numeral 171 denotes a capacitive coupling means for taking the power line communication signals generated by the communication means CBT in Figure 4 from the power supply line 2. These power line communication signals  
10 carrying the current threshold commands CC are received by the command interface IF and stored in the current threshold command memory MEM, as described above. A large variety of ready made products and solutions is available on the market for implementing power line  
15 communication systems. Any of these power line communication solutions can be adopted for transmitting current threshold commands CC to the electric circuit breaker 1, such that a detailed description of power line communication technology may be omitted here.

20  
Figure 6 shows a third embodiment of an electric circuit breaker 1 according to the present invention. This embodiment differs from the embodiment of Figure 5 in the provision of energy metering means 18 for measuring  
25 and counting the energy drawn by the consumer from the power distribution network through the power supply line 2. In the embodiment shown in Figure 6, the energy metering means 18 receive a current level detection signal CL from the current detector 15. The energy  
30 metering means 18 calculates the energy from the detected current level CL and the detected supply

voltage U and accumulates at least the active energy drawn from the power supply network. The accumulated amount of energy is displayed on a display 19. All other components of the electric circuit breaker 1 of the embodiment of Figure 6 correspond to the components shown in the second embodiment of Figure 5. In this respect, reference is made to the description already given above.

Figure 7 shows an advantageous embodiment of the means 13 for causing the switch to break the electrical circuit in response to a tripping signal. This embodiment is suitable for any of the circuit breaker embodiments herein described. In Figure 7, elements similar to or identical with elements shown in the preceding figures have been denoted with the same reference numerals. With regard to these elements reference is made to the description given above. In the embodiment of Figure 7, the means 13 comprises an electromagnetic coil 131 which is connected to receive the tripping signal 14 from the processing means 16. The coil 131 magnetizes a movable element 132 which is mechanically coupled to the contacts 111 of the switch 11. Moreover, the movable element 132 is also coupled with the lever L for manually operating the switch 11. Reference numeral 133 denotes an auxiliary switch mechanically coupled with the movable element 132. The auxiliary switch 133 is connected in series with the coil 131, such that the energization of the coil 131 by the tripping signal 14 depends on the state of the auxiliary switch 133. Reference numeral 011 denotes a

displacement of the movable element 132, e.g. an angle, which is required to open the contacts of the switch 11. Similarly,  $\theta_{133}$  denotes a displacement of the movable element 132, e.g. an angle, which is required to open the auxiliary switch 133. According to the embodiment shown in Fig. 7, the switch 11 and the auxiliary switch 133 are constructed such that the displacement  $\theta_{133}$  required to open the auxiliary switch 133 is larger than the displacement  $\theta_{11}$  required to open the switch 11.

When the processing means 16 generates a tripping signal 14, this will energize the coil 131 until the displacement of the movable element 132 is large enough to open the auxiliary switch 133. This displacement will then surely be large enough to reliably open the contacts 111 of the switch 11. At the same time it is achieved that a current through the coil 131 will be neither higher nor lower than necessary and will not flow longer than necessary for reliably opening the switch 11. The duration for which the processing means 16 generates the tripping signal 14, is uncritical.

According to an advantageous modification of this embodiment, the mechanical coupling of the lever L with the switch 11 is made dependent on whether the coil 131 is energized or not. If the coil 131 is energized, then the lever 11 is decoupled from the switch 11. To this end an electromagnetic coupling element (not shown) can be provided for selectively coupling or decoupling the lever L from the switch contacts 111. The electromagnetic coupling element can have a movable hook, cam, tappet or any other engagement means which

can be biased e.g. by means of a spring, to mechanically couple the lever L with the contacts 111 of switch 11. The electro magnetic coupling element has means to electro magnetically withdraw the engagement means to decouple the lever L from the switch contacts 111 when the coil 131 is energized. When the processing means 16 outputs a continuous tripping signal, for instance in response to an external circuit interrupt command (which has caused the switch 11 to break the electrical circuit 3) and a user then tries to move the lever L into the closed position of the switch 11 to re-establish the electrical circuit 3, this will result in that the auxiliary switch 133 will close before the switch 11 can close, due to the fact that because the displacement required to open the auxiliary switch 133 is larger than the displacement required to open the switch 11, the switch 133 will close earlier than switch 11 can close. This will then energize the coil 131 and decouple the lever L from the switch contacts 111 before the switch contacts 111 can close the electrical circuit. The energized coil will furthermore generate a force upon the lever L which is perceivable by the user, to urge the lever back into the open position. On the other hand, if there is no longer a tripping signal from the processing means 16, the lever can be moved back into the closed position.

The electromagnetic coupling element (not shown) can either comprise its own actuator (e.g. a coil) electrically connected in series with the coil 131, or the electromagnetic coupling element can be connected

into the magnetic circuit which is energized by the coil 131, such that whenever the coil 131 magnetizes the movable element 132, a magnetic force is exerted also upon the engagement means to withdraw from engagement  
5 with the switch contacts 111.

Figure 8 shows a flow diagram to illustrate the operation of an embodiment of the processing means. In this embodiment, the processing means comprises a micro  
10 processor and associated program and data memory, as well as input/output port facilities. Such hardware structures are available on the market e.g. in the form of embedded micro controller solutions wherein the micro processor as well as the required peripheral devices  
15 like memories and I/O ports are integrated on a single chip. The embodiment shown in Figure 8 is but one of a large variety of possible implementations of the processing means 16 in any of the previously described embodiments of the electric circuit breaker 1, as will  
20 be readily apparent to those skilled in the art. In this embodiment, the micro processor in the processing means 16 is programmed to perform the flow of operations shown in Figure 8. This flow of operations achieves the processing of the detected current level CL and the  
25 generation of the tripping signal 14 depending on a stored programmed current threshold command maintained in the memory MEM, which indicates a programmed current threshold I<sub>j</sub> and the associated response time T<sub>j</sub>. The flow of Figure 8 implements a retriggerable measurement  
30 of the duration of an overload condition when the detected current level CL is above the current threshold



$I_j$ , wherein a non-steady overload condition will not lead to the generation of a tripping command 14, as will be explained in the following.

5 S1 in Figure 8 denotes an operation to initialise an incremental index  $i$  to take the value 1. This incremental index will be used to identify one of  $K$  sub-intervals  $T_i$  of the programmed response time  $T_j$ . The flow of operation in Figure 8 queries for each of the  $K$   
10 sub-intervals  $T_i$  whether the overload condition prevails. If and only if the overload condition was present for  $K$  successive sub-intervals  $T_i$ , the tripping signal 14 will be generated to break the electrical circuit 3.

15 In the operation S2 of Figure 8, a timer is loaded with the value  $T_i$ . The operation S3 serves to check whether the timer set in the operation S2 has expired (branch Y) or not (branch N). After the expiry of the sub-interval  
20  $T_i$ , the flow proceeds to the operation S4 wherein it is checked whether the current level  $CL$  is larger than the programmed current threshold  $I_j$ . In the negative case (branch N), the flow returns to the operation S1 to reinitialise the incremental index  $i$ . In the affirmative  
25 (branch Y of operation S4), the flow moves on to the operation S5 in order to increment the index  $i$ . Then, in operation S6 it is checked whether the incremental index exceeds a value  $K$  which satisfies the condition that  $K$  times  $T_i$  equals the programmed response time  $T_j$ . In the  
30 negative, the overload condition did not yet prevail for more than the programmed response time  $T_j$  and the flow

returns to the operation S2. In the affirmative (branch Y), the flow proceeds to the operation S7 to generate a tripping command, that is the tripping signal 14 of the processing means 16.

5

The flow of operations shown in Figure 8 can be initiated as an interrupt routine which will be executed whenever the current detector 15 indicates that a programmed current threshold  $I_j$  has been exceeded. In the alternative, the flow of Figure 8 can be executed repeatedly at regular time intervals, e.g. triggered by a timer interrupt, or the flow of operations S1 to S7 can be implemented as a subroutine repeatedly called by other software routines implemented for execution on the micro controller, e.g. in a polling mode. If the current threshold command indicates a plurality of programmed current thresholds  $I_j$  and associated response times  $T_j$ , as shown e.g. in Figure 3b, the flow of operations in Figure 8 will be executed for each programmable pair of current thresholds  $I_j$  and associated response times  $T_j$ .

Figure 9 shows an advantageous extension which provides a safety check when a tripping signal has been generated, in order to confirm that the detected current level CL has a matter of fact reached zero. In the operation S8 it is checked whether an active tripping signal is present. As soon as a tripping signal exists (branch Y in the operation S8), a check is made whether the current level CL has reached zero. In the negative case (branch N in the operation S9), the flow proceeds to the operation S10 to set an alarm condition because

of the detection of a current level larger than zero despite the generation of a tripping command for the switch 11. This alarm condition can be an audio and/or visual indication at the electric circuit breaker 1.

- 5 More preferably, the electric circuit breaker 1 comprises means to report this alarm condition to the communication means CBT and/or to the central administration and control facilities 21 which will then take appropriate action.

10

- Figure 10 shows a further embodiment of the current detector 15 and the processing means 16 in any of the Figures 2, 5 and 6. In the embodiment of Figure 10, reference numeral 152 denotes a current transducer for transducing the current flowing through the power supply line 2. 153 denotes a converter for performing a root mean square conversion of the current detected by current transducer 152, and to generate a current level detection signal CL. 163 denotes a filtering and averaging circuit comprising an RC element for averaging and delaying the current level detection signal CL. 164 denotes a circuit for transforming the programmable current threshold into a reference voltage  $V_{ref}$ , e.g. by means of using a digital potentiometer, as such well known in the art, which converts the digital current threshold value into a tap position of the potentiometer. 165 denotes a comparator circuit which compares the output signal of the filtering and averaging circuit 163 with the programmed reference voltage  $V_{ref}$ . 166 denotes a driver circuit, e.g. a MOSFET transistor or bipolar transistor which receives
- 15
- 20
- 25
- 30

at its gate the output signal from the comparator circuit 165. As soon as the output signal of the circuit 163 exceeds the programmed reference voltage  $V_{ref}$ , the comparator circuit 165 generates a gate signal such that  
5 the transistor 166 turns conductive and causes a tripping current to flow through the means 13 which will then cause the switch 11 to break the electrical circuit. In this embodiment, the elements 163, 164, 165  
10 implement the processing means 16 using hardware components.

Figure 11 shows yet another embodiment of the current detector 15 and the processing means 16. Elements similar to the elements shown in Figure 10 are denoted  
15 with the same reference numerals. With respect to these elements reference is made to the description of Figure 10. In Figure 11, 1631 denotes a voltage frequency converter for converting the current level detection signal CL into a corresponding frequency. 1632 denotes a  
20 frequency divider which divides the frequency provided by the current frequency converter 1631 by a factor determined by the programmed current threshold stored in the memory MEM of the electric circuit breaker 1. The frequency divider outputs a divided signal ck for  
25 clocking a counter 1651. 1642 denotes a circuit for converting the programmed time interval associated with the programmed current threshold from the stored digital representation in the memory MEM into a signal for controlling the frequency of an oscillator 1641. The  
30 oscillator 1641 outputs a reset signal to the counter 1651 with a frequency in accordance with the programmed

time interval  $T_j$ . If the output signal of the frequency divider CK occurs with a frequency higher by a given factor than the frequency of the reset signal, the counter 1651 will output an overflow signal to the driver transistor 166 in order to generate the tripping signal.

Accordingly, the embodiment shown in Figure 11 implements the processing means 16 in hardware such that the processing means 16 can generate the tripping signal 14 depending on a stored programmable current threshold command indicating a current threshold  $I_j$  and an associated response time interval  $T_j$ , and depending on the detecting current level flowing in the electrical circuit 3.

The embodiments so far described comprise a switch 11 ; which can be tripped by the first means 13 and also by the second means 12 advantageously provided as a back up. The switch 11 can be a mechanical switch with movable contacts 111 to break or close the electric circuit. Alternatively, the switch 11 can be composed of a series connection of a mechanical switch and a solid state switch, e.g. a triac. The mechanical switch is mechanically coupled with the second means 12, and the solid state switch receives a control signal from the first means 13 in accordance with the tripping signal 14 from the processing means 16.

In the embodiments described above, the breaker characteristics are achieved by detecting the current

flowing through the electric breaker, and controlling the breaker switch in accordance with one or more programmable current thresholds and related response time intervals. Thermo-magnetic characteristics of the breaker can be provided as a safety margin, while the actual operating thresholds can be programmed into the electric breaker. This allows to make the trigger threshold dependent e.g. on the present load in the electricity distribution network, on the time of day, or on more complex parameters like type of customer (e.g. hospital versus private consumer) and the present load situation in the electricity distribution network. The programmable electric breaker thus allows a remote adaptation to changes in the supply contract and/or effective counter measures in emergency situations, e.g. when approaching the maximum load which the network can bear.

While the embodiments described above are based on a detection of the current flowing in the electrical circuit 3, the skilled person will understand that it would be possible to achieve essentially the same effects if instead of or in addition to the detection of the current flowing in the circuit 3, the active and/or reactive power fed into the electrical circuit 3 is detected. Similarly, the programmable current thresholds described above may define current thresholds or power thresholds or a suitable complex entity composed of current and power. Whenever the foregoing description refers to the detection of current levels or the programming of current thresholds, the term current

is to be understood in this more general sense.  
Reference signs in the claims shall not be construed to  
limit their scope.